Laser Cooled Atomic Clocks in Space

laser cooling

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Overview of LCAP Flight Projects

•PARCS (Primary Atomic Reference Clock in Space):

Development of a laser cooled and trapped cesium clock for the realization of the unit of time, to operate continuously for at least 30 days. Use of orbiting clock for relativity experiments and global precise time distribution.

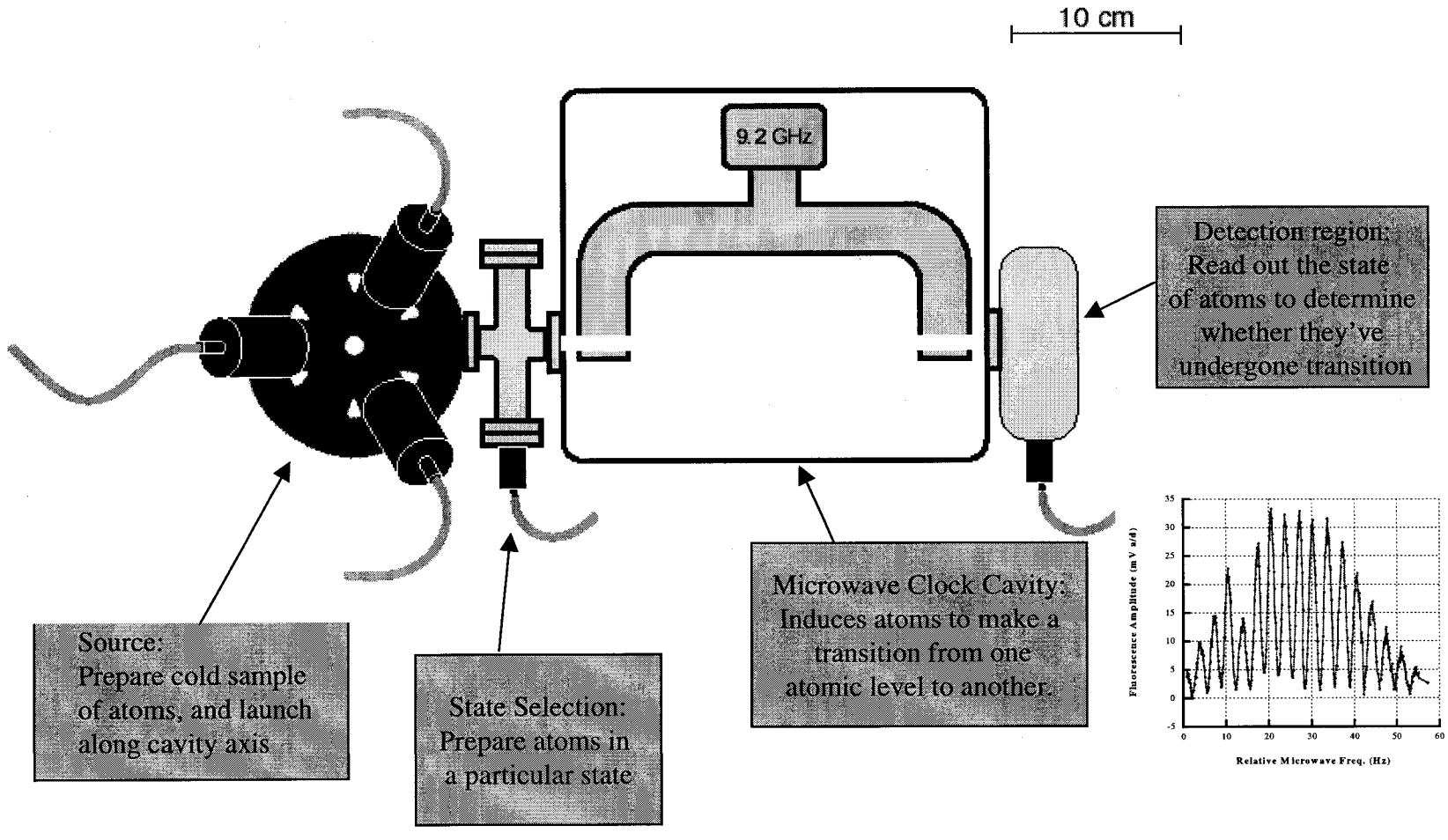
•RACE (Rubidium Atomic Clock Experiment):

Development of a laser cooled and trapped Rubidium clock for ultrahigh accuracy (exceeding a part in 10^{16}), to operate continuously for at least 30 days. Use of clock for relativity experiments and cold collision studies.

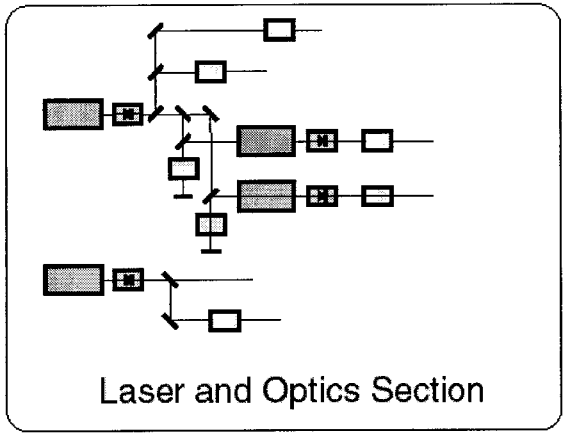
•GLACE (Glovebox Laser cooled Atomic Clock Experiment):

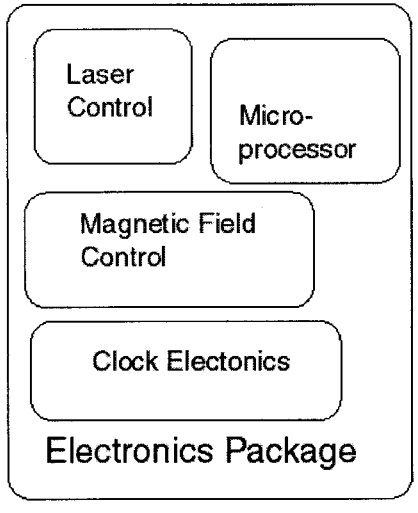
Demonstration of laser technology for future LCAP flights, as well as a test of laser cooling techniques in microgravity, in particular those required for the LCAP clock experiments.

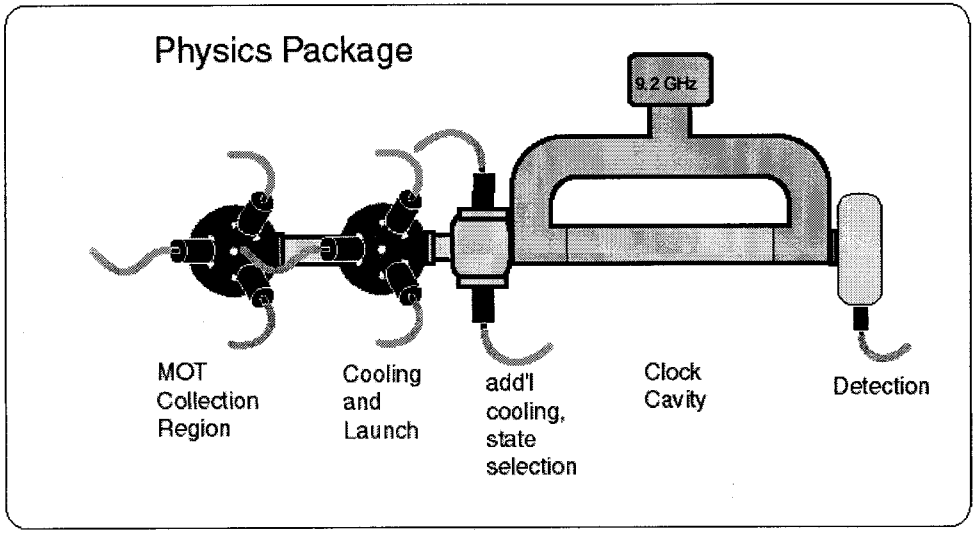
Space Clock 101



LCAP Instrument Block Diagram



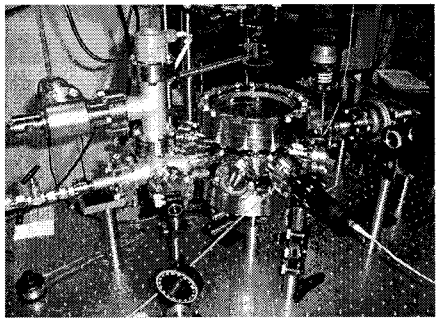


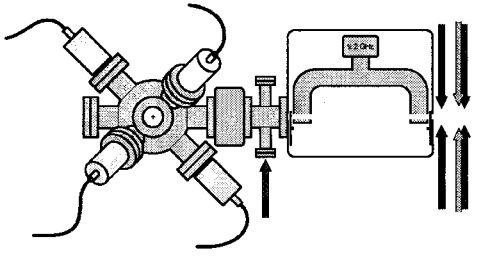


Physics with Clocks in microgravity

- Gravitational frequency shift
- Local Position Invariance
- Kennedy-Thorndike Experiment

LCAP Timeline





JPL Laser Cooling Facility created

Mar 97

Two Flight definition projects selected from '96 NRA (PARCS and RACE)

Nov 97

Ground-based prototype clock operational

Sept 00

Flight Unit complete. Astronaut training begins

Sept 02

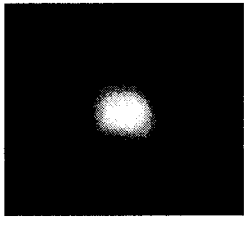
Launch

April 03

May 03

Oct 97

First trapped Cs images at JPL



Jan 99

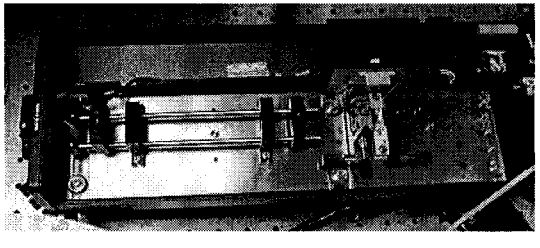
PARCS project passes its SCR

May 01

Space Qualification of components complete

Sept 01

Engineering model complete.

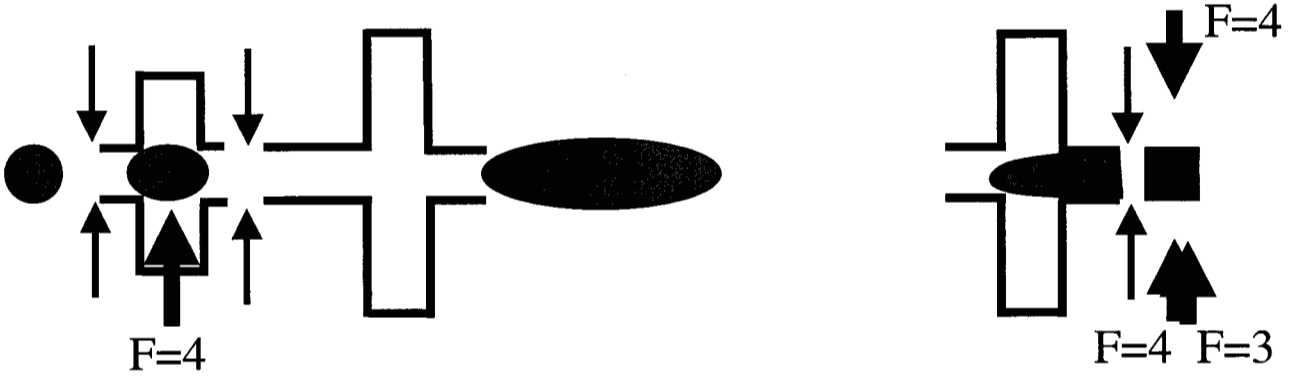


Mar 03

Integration into Express Transportation Rack

Integration into Shuttle MPLM

Clock Operation: Example



Collect: $N_0 = 8 \times 10^7$ cold atoms/ball
Launch: $N_{m=0} = 9 \times 10^6$ in m=0 with 2 balls/s
Detect: $N_D = 1.5 \times 10^4$
Ramsey Time: $T_R = 5$ s
Cycle Time: $T_c = 15$ s

» $\sigma_y(\tau) = 1.6 \times 10^{-14} \tau^{-1/2}$

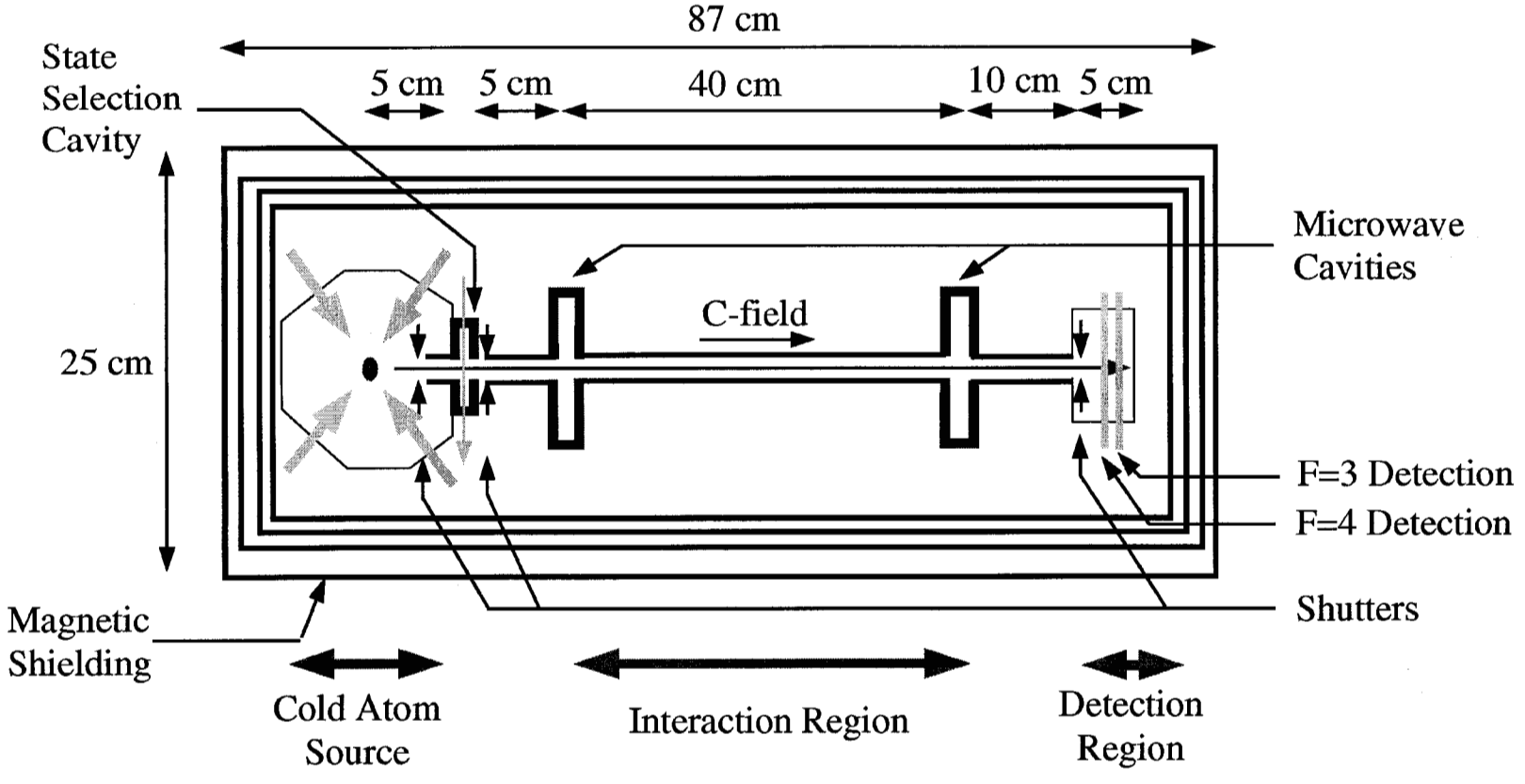
Source "brightness" achieved so far:

1) $N_0 \sim 2 \times 10^8$ (in 1 sec.) in vapor cell molasses (Ch. Salomon, Paris)
2) $N_0 \sim 5 \times 10^7$ (in 1 sec.) in small beam filled molasses (NIST Fountain)

PARCS

Basic Clock Layout

NIST JPL



GLACE: Glovebox Laser-cooled Atomic Clock Experiment

Principle Investigator: K. Gibble (Yale)

Goals:

- First utilization of tunable, frequency-stabilized lasers (300 kHz @ 852 nm) in space.
- Demonstrate laser cooling and trapping in microgravity.
- Demonstrate longest 'perturbation-free' interaction time for a precision measurement on neutral atoms.
- Resolve Ramsey fringes 2–10 times narrower than achievable on Earth.

Approach:

- COTS components (HP 5071 cavity, commercial lasers and vacuum components).
- Utilize prototype hardware from LCAP flight definition experiments.

Launch date: Oct. 2002 (UF-3)

Space Qualification of Components

Shuttle requirements:

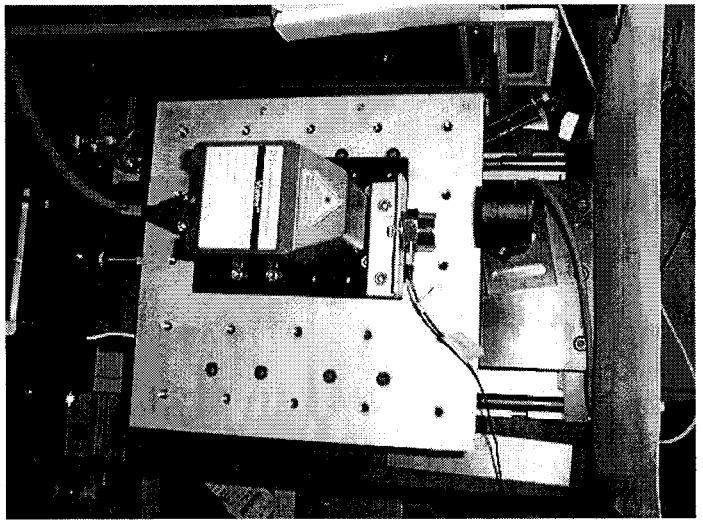
•Vibration Testing:

Freq. Range	Design/Protoflight (PF)	Flight Acceptance (FA)
20 to 150 Hz	+6dB/Octave	+6dB/Octave
150 to 1000 Hz	0.06 g2/Hz	0.03 g2/Hz
1000 to 2000 Hz	-6dB/Octave	-6dB/Octave

Duration: Design: 2 minutes; PF or FA test: 1 minute

•Temperature:

Must survive over a -5 to 50 C range



New Focus Vortex laser on vibration test bed at JPL

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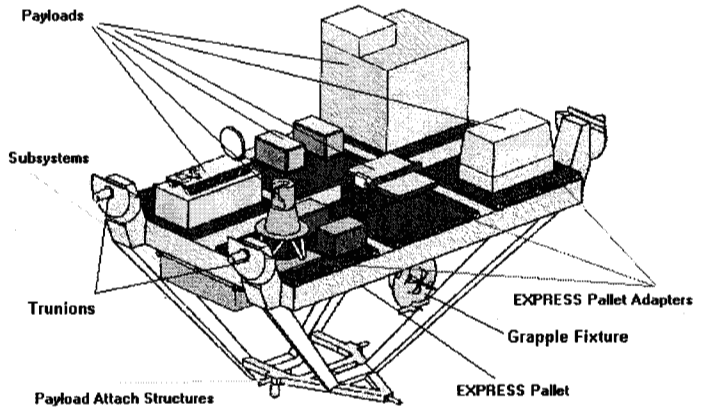
ISS Science Platforms:

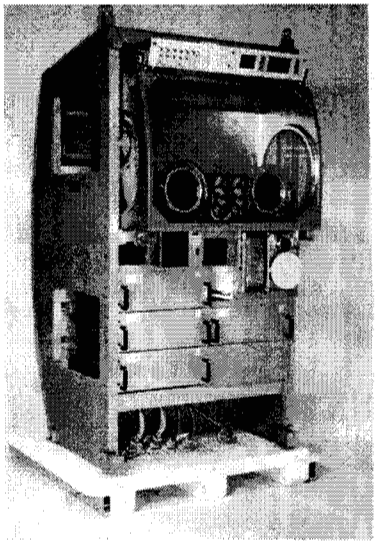
Express Pallet

- For External Payloads



Microgravity Science Glovebox(MSG)

- 260 liter working volume



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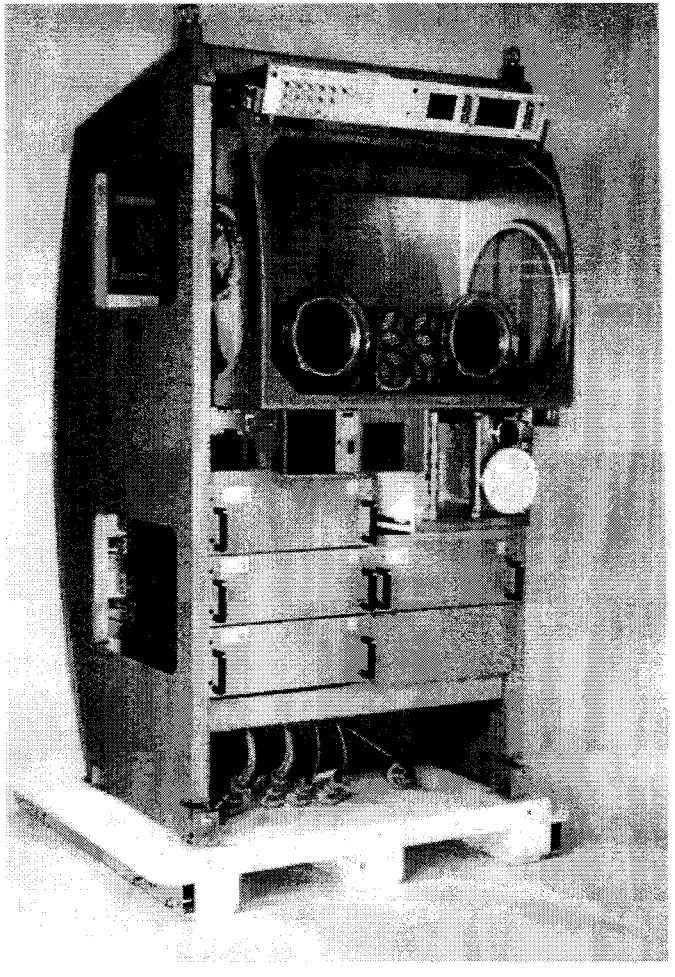
Microgravity Science Glovebox



MSG specifications

- **Working volume**:
  260 liters (92 cm×65 cm×50 cm)
- **Vibrational isolation**:

Frequency Range	RMS Acceleration
0.01–0.1 Hz	< 0.21920 μg
0.1–100 Hz	< f×0.21920 μg/Hz
100–300 Hz	< 219.20 μg

- **Electrical power**
  1000 W (8.3 A @ 120 V, 7 A @ 28 V, 2 A @ ±12 V, 4 A @ 5 V)
- **Heat dissipation**
  1000 W (800 W via coldplate, 200 W via air flow)
- **Data I/O**
  RS-422, MIL STD 1553B, digital I/Os, analog outputs, ethernet.

JPL